SE9400136

Studsvik Report

STUDSVIK/M-93/70

PSM 3-1

RESULTS FROM LOW CYCLE FATIGUE TESTING OF 316L PLATE AND WELD MATERIAL

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STUDSVIK/M-93/70

1993-04-23 7405

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Abstract

Specimens for low cycle fatigue testing from the second heat of the CEC reference 316L plate and from Tungsten Inert Gas (TIG) weld material have been neutron irradiated near room temperature to a displacement dose of approximately 0.3 dpa. The low cycle fatigue testing of both irradiated and unirradiated specimens was performed at 75, 250 and 450°C, and with strain ranges of 0.75, 1.0 and 1.5%.

There is no clear effect of the irradiation on the low cycle fatigue properties. For the weld material the endurance is shorter than for plate, and the dependences on temperature and strain range are not clear.

The present work was supported by the Swedish Natural Science Research Council (NFR) and the European Atomic Energy Community under Association Contract No 345-88-1.

Checked by

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Contents

1. Introduction

Type 316L steel is considered as one of the candidate materials for the first wall of the Next European Torus (NET). The design studies of NET have indicated a choice of low pressure water as a coolant for the first wall, resulting in a minimum temperature of the first wall of 100°C or slightly lower. At temperatures below 100°C neutron irradiation can have a marked effect on the mechanical properties of austenitic steels already at a damage level of 0.3 dpa, which is typical of the initial physics phase of NET (1).

The present work was initiated in order to provide supplementary data on low cycle fatigue (LCF) properties after neutron irradiation near room temperature. Specimens from welds were included since a certain amount of welding will be required for the construction of the first wall, and since weld materials are less ductile than plate material.

2. Experimental

2.1. General

The experimental variables used in the experiments are the following:

- Plate / Weld
- Unirradiated / Irradiated
- Testing temperature
- Strain range

Altogether thirty specimens have been tested according to the test matrix in Table 1.

Table 1
Parameter matrix and specimen numbers for the investigation

Temperature [°C]	Strain range [%]	Unirradiated material		Irradiated material	
		Plate	TIG[1]-weld	Plate	TIG-weld
75°C	0,5	P42			
75°C	0,75	P45			
75°C	1,0	P40	M31	P34	M26
75°C	1,5	P41	M32	P37*	M23*
250°C	1,0	P47	M34	P36	M27
250°C	1,5	P44	M33	P33	M24
450°C	0,75	P51	M35	P25	M22
450°C	1,0	P49	M36	P31	M29
450°C	1,5	P50	M37	P26	M25

* Tested at 25°C

The sequence of the experimental work was:

* manufacturing the specimens from the plate and the welded material
* irradiation
* low cycle fatigue testing

[1] Tungsten Inert Gas

2.2. Material

The material investigated was a part of the second heat of the CEC reference 316L-167 SPH material in solution-annealed condition[2]. A low carbon content gives the material good microstructural stability during welding, and reduces the risk of intergranular cracking. Sufficient strength is obtained by compensating the reduced carbon content by a higher nitrogen content.

The material was tested in two forms:

* plate
* TIG-weld material, which was received in the form of a weld metal deposit with a minimum width of 49 mm. It was manufactured by the Danish Welding Institute (2).

The chemical compositions of the plate and the TIG-weld material are shown in Table 2.

Table 2
Chemical composition of plate and TIG-weld.

	Element									
Material	C	Si	Mn	Cr	Ni	Mo	Cu	Co	N	Fe
Plate	0,02	0,35	1,75	17,2	12,2	2,3	0,07	0,08	0,07	bal.
TIG-weld	0,04	0,36	1,82	16,3	8,98	2,16	0,04			bal.

[2] Supplied from Creusot-Loire-Industrie, Usine de Creusot. The heat number was 12879 and the plate number was R-33688

2.3. Specimens

The specimen design and detailed dimensions are shown in Figure 1.

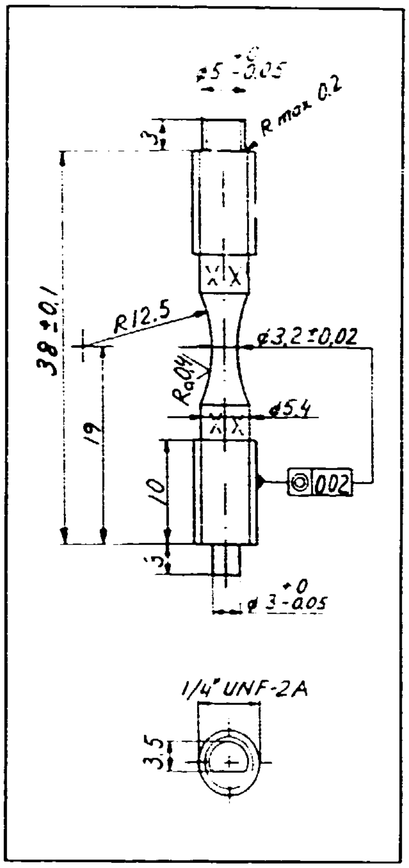

Figure 1
Low cycle fatigue specimen.

The specimens were cut according to Figure 2. The specimens from the weld were located with the axis perpendicular to the weld.

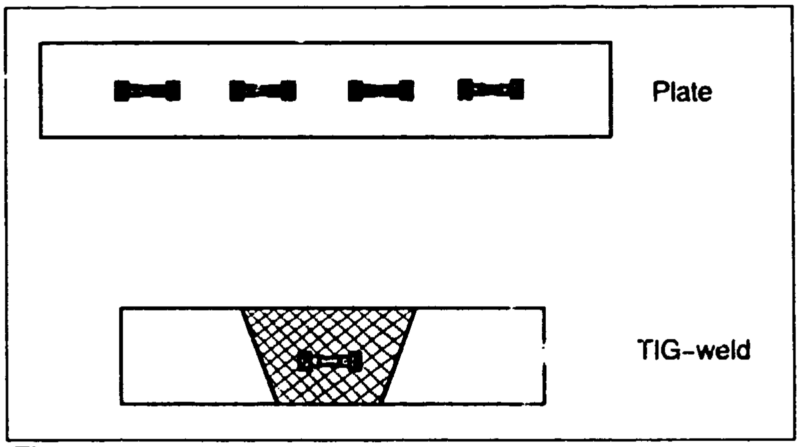

Figure 2
Location of the specimens in the plate and in the weld. The specimens were all oriented in the transverse direction.

2.4. Irradiation

The irradiation of the specimens was performed in the Studsvik R2 reactor. The specimens were irradiated directly in flowing water of about 35°C for about 2000 h (five reactor cycles). The fast neutron dose received corresponds to a damage level of about 0.3 dpa. The hydrogen and helium production was 4.7 and 0.45 appm respectively. The gamma heating of the specimens was less than 3 W/g.

The irradiation procedure is described in Ref 3.

2.5. Low cycle fatigue testing

The hour-glass specimens were tested in a servo-hydraulic materials testing machine. The minimum diameter of the specimen was monitored by means of a scissors-type extensometer. The tests were performed under constant diametral strain amplitude since a suitable computer for axial strain control was not available. The diameter strain amplitude was adjusted to give axial strain ranges close to 0.75, 1.0 and 1.5%. A symmetric triangular wave shape was used with three different load cycling frequences, 0.066 s^{-1}, 0.05 s^{-1}, and 0.033 s^{-1} (15, 20 and 30 seconds per cycle). These frequences gave a strain rate of 10^{-3} s^{-1} at all tests.

The actual axial strain (ε) is influenced by the stress (σ) and the Poissons value (ν) according to:

$$\varepsilon = \sigma/_E * (1 - 2\nu) + |2\varepsilon_d|$$

where ε_d = diametral strain.

Before testing of each specimen the ν-value was evaluated by the relation

$$\nu = \varepsilon_d \cdot \frac{E}{\sigma}$$

which is valid in the elastic range. For anisotropic material, with varying E, the ν-value differs depending on how the specimen is located in the material.

The influence of ν and σ on ε is small.

The axial strain range is somewhat changed during the test as the maximum stress changes due to strain hardening or softening. For each specimen a representative value of the actual axial strain range is obtained according to the above equation with the maximum stress at half the time to failure ($N_f/2$).

3. Results and discussion

3.1. General

The results for all specimens are tabulated in Appendix A:
the total strain range ($\Delta\varepsilon$), the maximum stress at $N_f/2$ (σ) and the number of cycles to failure (N_f).

The results from the investigation can be summarized by means of the relation between the number of cycles to failure and the axial strain range, see Figure 3. From the curves some conclusions can be drawn about the behaviour of the four types of specimens at different temperatures and strain ranges.

The fatigue endurances of the plate material specimens appear to be represented by two curves, one for the 75°C and 250°C data and one for the 450°C data. The results from the TIG-weld specimens are scattered and indicate in general a lower fatigue endurance than the plate material. The irradiation to 0.3 dpa has hardly any effect on the fatigue properties under the present testing conditions. A few data points among the weld specimens indicate a slight improvement.

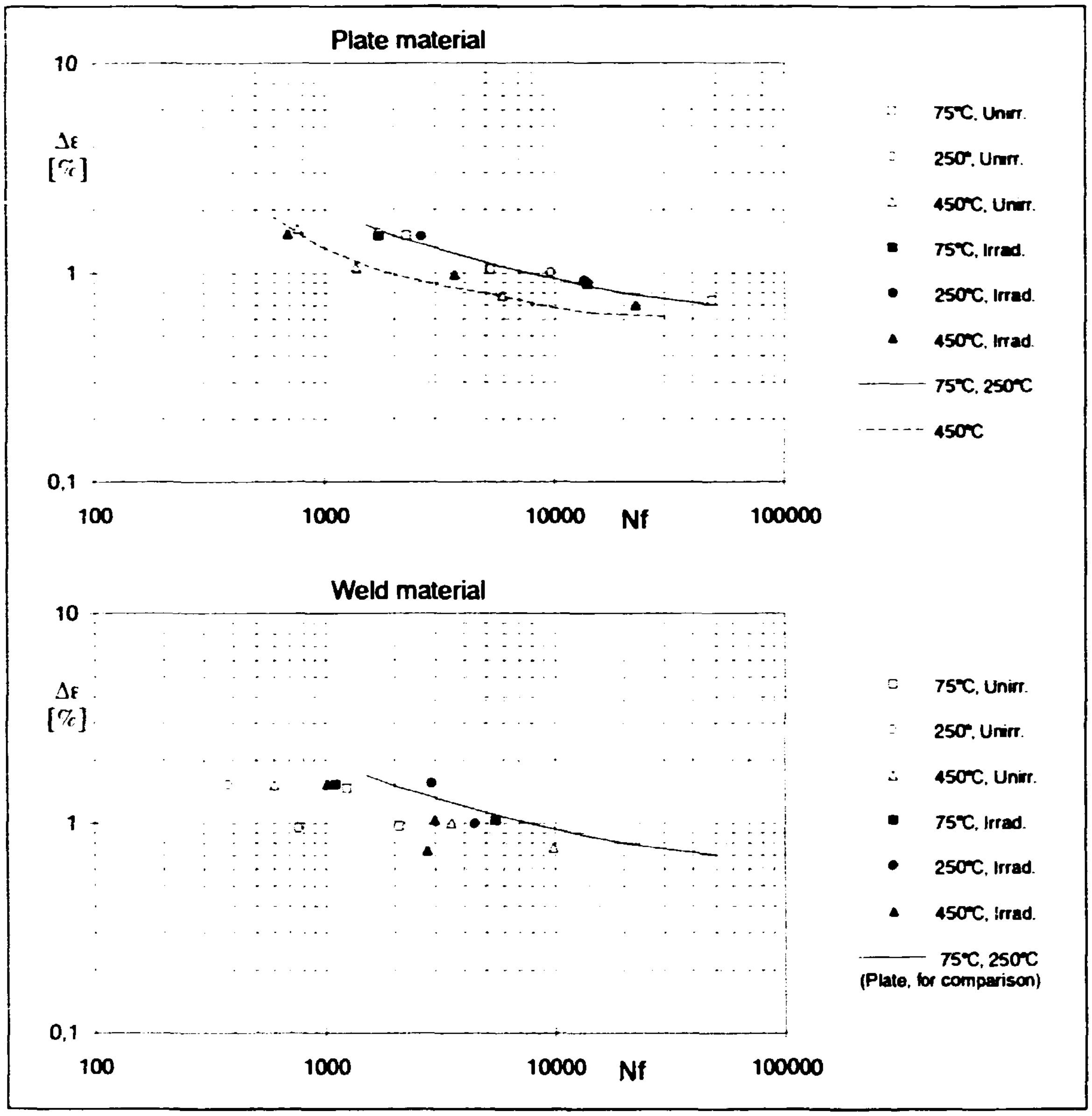

Figure 3
Strain range versus endurance life for all specimens.

3.2. Stress – time curves

Examples of typical maximum stress versus time curves are shown in Figure 4. They represent four material conditions (unirradiated plate, irradiated plate, unirradiated weld, irradiated weld) tested at a strain range of 1.5% and at 450 °C.

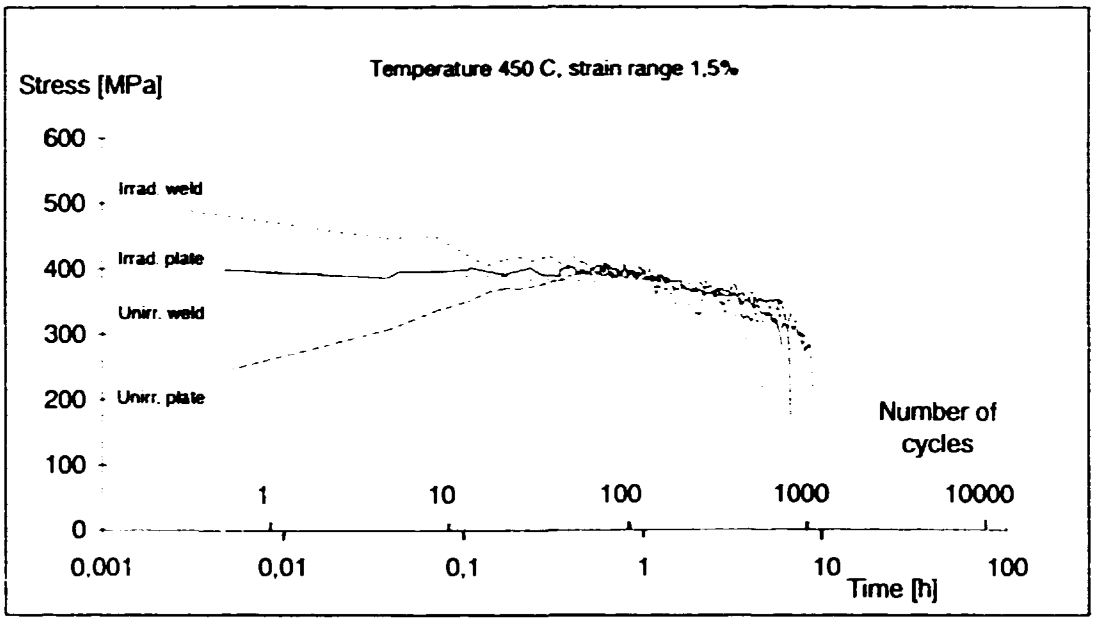

Figure 4
Maximum stress versus time for unirradiated plate, unirradiated weld, irradiated plate, and irradiated weld (specimen P50, M37, P26, and M25 respectively) tested at a strain range of 1.5% and at 450°C.

The figure shows the typical character of the curve for each material. Three types of curves can be seen:

a. The unirradiated plate material exhibits strain hardening during the first half-hour testing, whereafter the stress planes off at about 400 MPa during one hour and then decreases slowly during the rest of the testing.

b. The irradiated plate material and the unirradiated weld material have initially a higher density of lattice defects, which limits the strain hardening. The stress starts already at about 400 MPa and remains there for some hours, whereafter it decreases.

c. The irradiated weld material, finally, starts at an even higher stress and softens during the test.

Appendix B shows the stress versus time curves for all specimens.

The above-mentioned differences at the initial part of the testing is also seen in the recording of hysteresis curves for the specimens. Figure 5 shows the axial stress versus axial strain during the first cycle for the same specimens as in Figure 4. After less then one hour the character of the hysteresis curves are similar for the specimens.

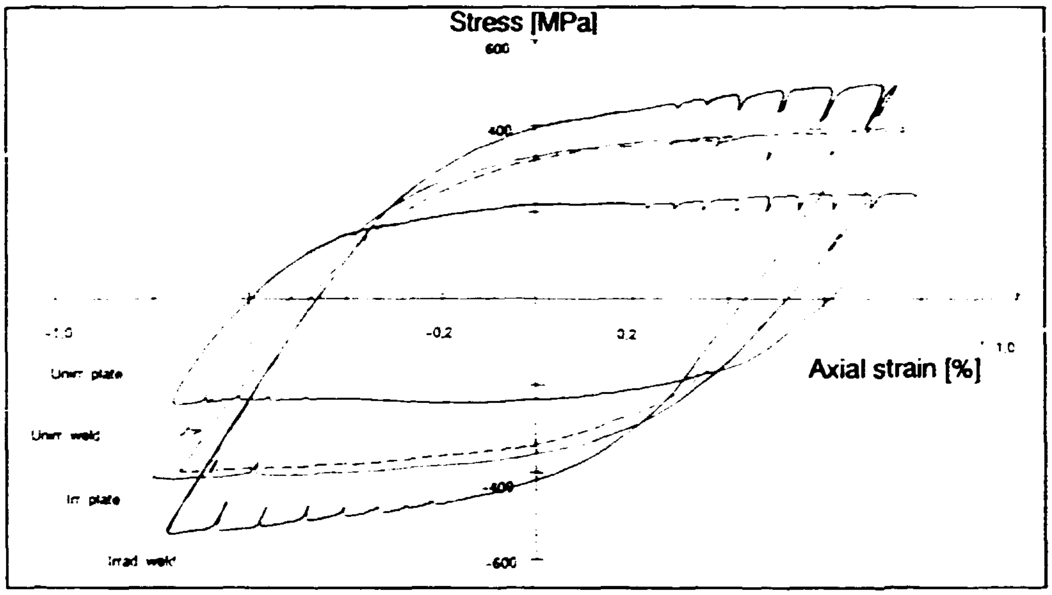

Figure 5
Hysteresis curves for stress versus strain for the first cycle for four specimens at 450°C and 1.5% strain. The specimens are the same as in Figure 4.

The axial stress at $N_f/2$ is in most cases nearly equal for the corresponding unirradiated and irradiated specimens, see Figure 6. Figure 4 shows that the irradiated weld specimens exhibit a cyclic softening during the initial phase of the tests. The plastic strain for these specimens are therefore smaller initially, which could contribute to the increase of the fatigue lives, which was seen for some cases in Figure 3. The temperature dependence and the general level of the $\Delta\varepsilon$ versus N_f curve is similar to results from an extensive investigation by B van der

Schaaf and J van Hoepen [4] and by M de Vries of the low cycle fatigue properties of DIN 1.4948 steel (AISI 304) [5].

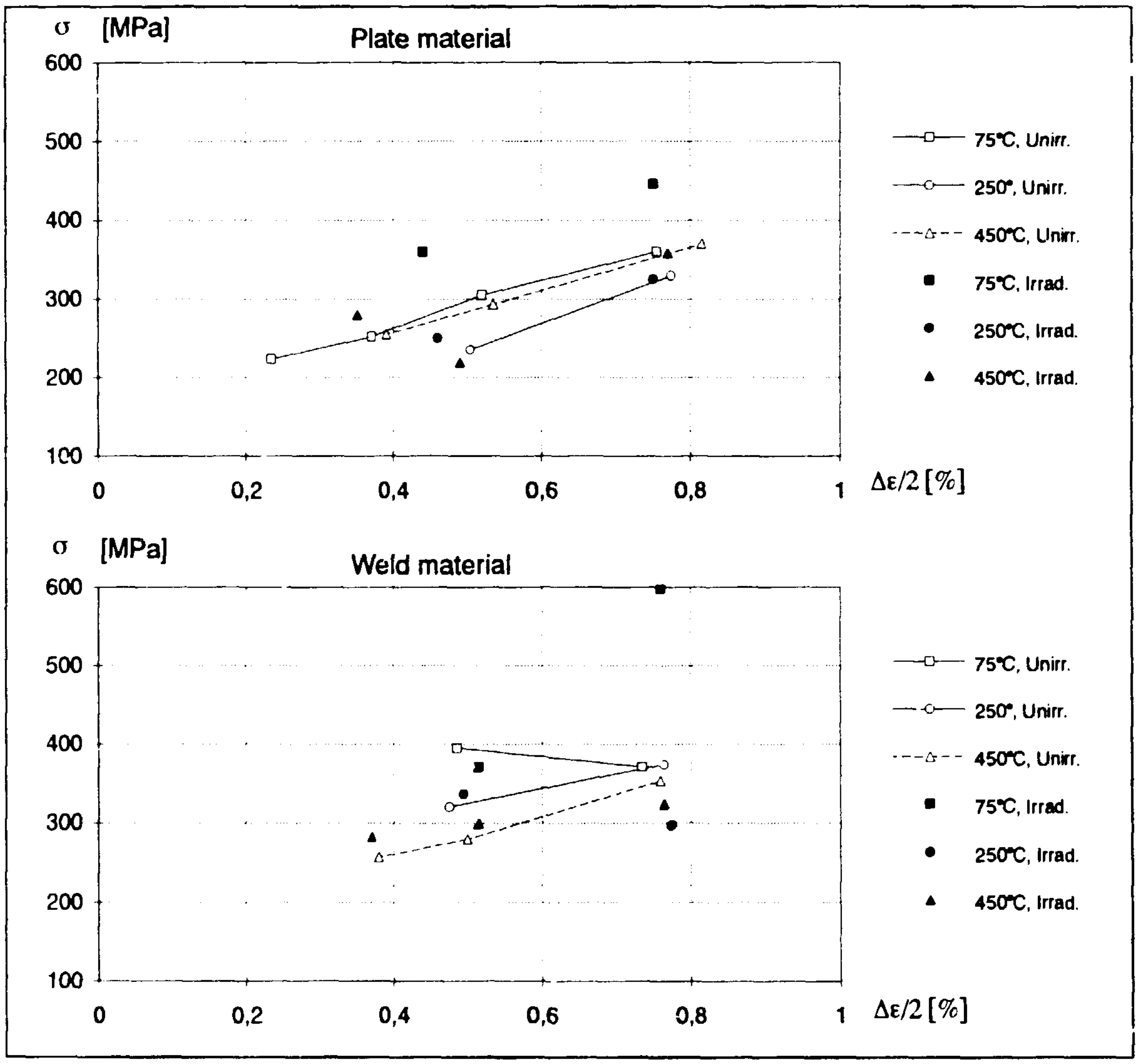

Figure 6
Stress versus strain range/2 at half endurance life.

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Effects of Radiation on Materials, Eleventh Conf. ASTM STP 782, 1982, p 665–689.

Results

Table A.1
Strain range and stress at Nf/2, and number of cycles for the plate specimens.

Temp-erature [°C]	Unirradiated specimens Strain range at $N_f/2$ [%]	Unirradiated specimens Max. stress at $N_f/2$ [MPa]	Unirradiated specimens Number of cycles N_f [-]	Irradiated specimens Strain range at $N_f/2$ [%]	Irradiated specimens Max. stress at $N_f/2$ [MPa]	Irradiated specimens Number of cycles N_f [-]
75°C	0,47	223	153909*			
75°C	0,74	252	47980			
75°C	1,04	305	5250	0,88	360	13845
75°C**	1,51	360	2256	1,53	446	1706
250°C	1,01	235	9620	0,92	250	13490
250°C	1,55	330	1720	1,50	325	2610
450°C	0,77	255	5921	0,70	280	22520
450°C	1,07	293	1359	0,91	219	3640
450°C	1,63	370	730	1,54	358	686

* No failure ** Irradiated specimen (P37) tested at 25°C

Table A.2
Strain range and stress at Nf/2, and number of cycles for the weld specimens.

Temp-erature [°C]	Unirradiated specimens Strain range at $N_f/2$ [%]	Unirradiated specimens Max. stress at $N_f/2$ [MPa]	Unirradiated specimens Number of cycles N_f [-]	Irradiated specimens Strain range at $N_f/2$ [%]	Irradiated specimens Max. stress at $N_f/2$ [MPa]	Irradiated specimens Number of cycles N_f [-]
75°C	0,97	395	2091	1,03	370	5500
75°C**	1,45	371	1240	1,52	598	1100
250°C	0,95	320	762	0,96	336	4440
250°C	1,48	374	378	1,55	297	2868
450°C	0,76	257	9870	0,74	283	2771
450°C	1,00	280	3516	0,99	299	2973
450°C	1,52	353	600	1,53	324	1016

** Irradiated specimen (M23) tested at 25°C

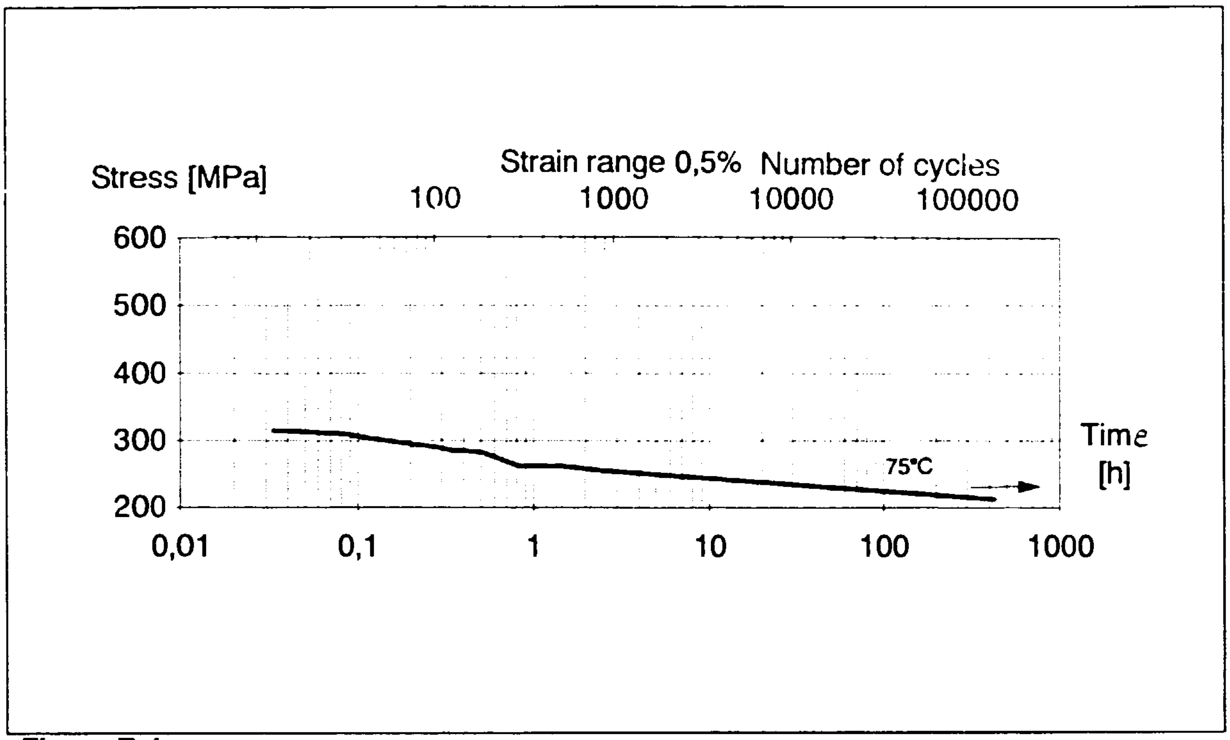

Figure B.1
Maximum stress versus time and number of cycles for unirradiated plate material at a strain range of 0.5%.

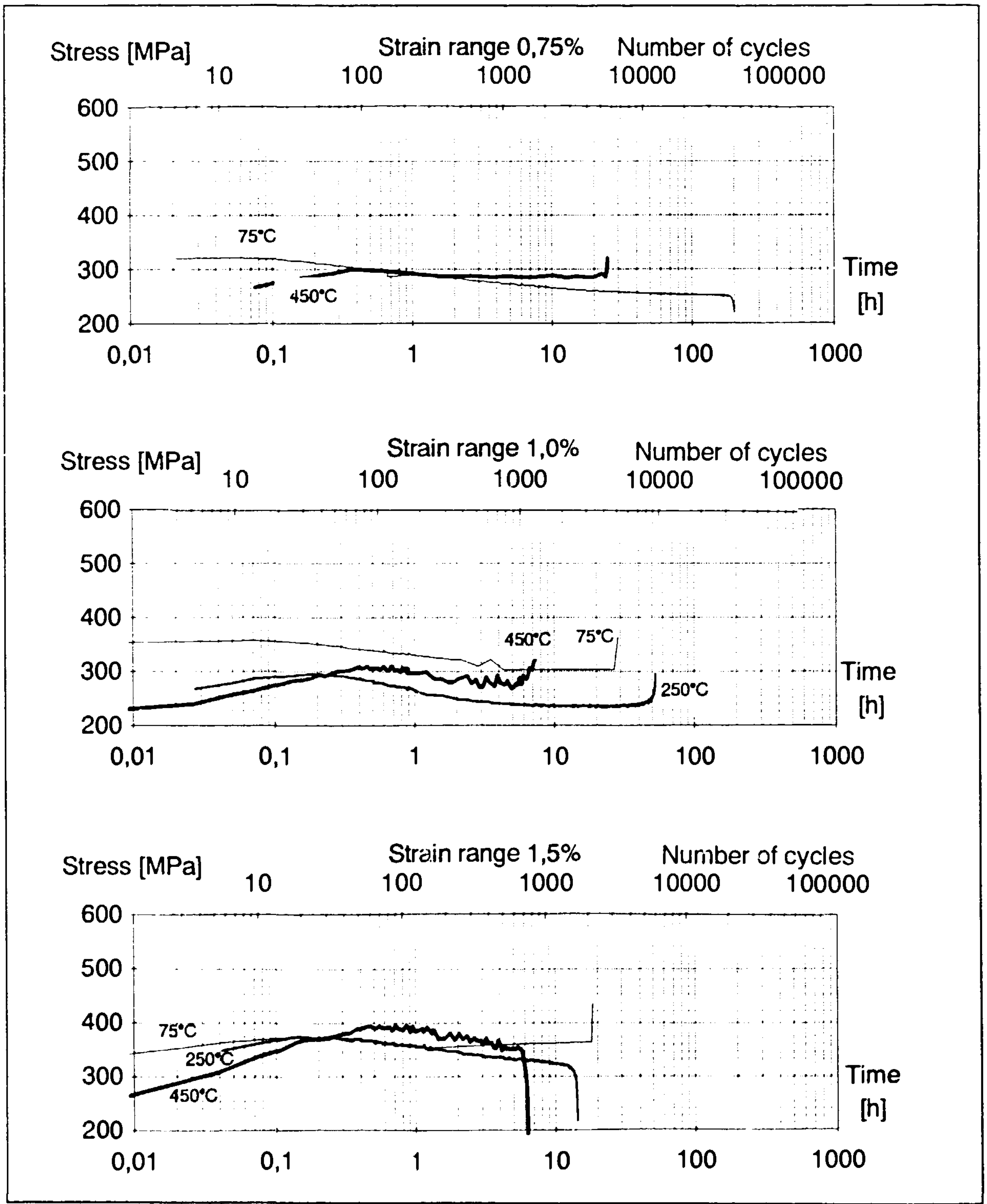

Figure B.2
Maximum stress versus time and number of cycles for unirradiated plate material.

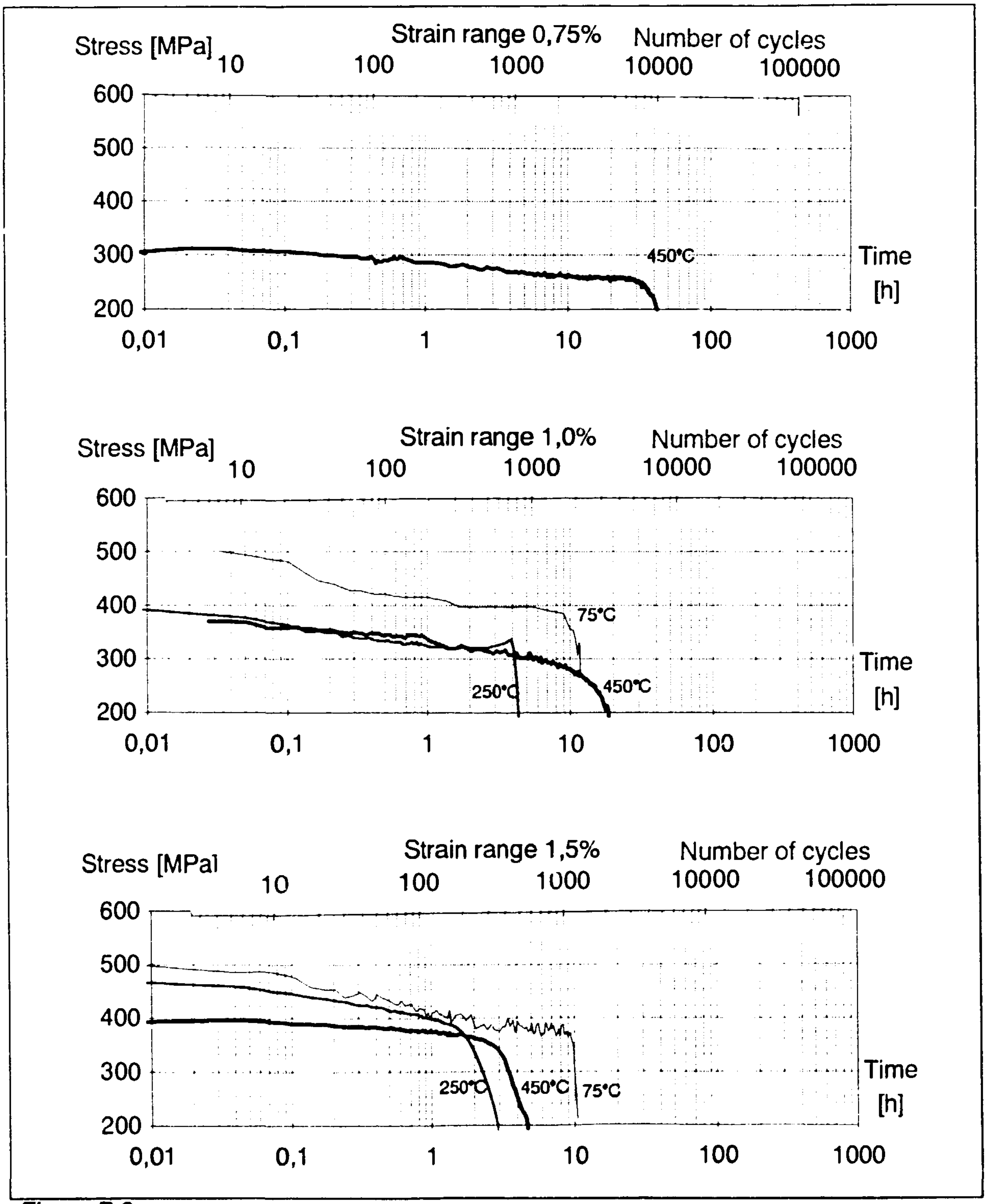

Figure B.3
Maximum stress versus time and number of cycles for unirradiated weld material.

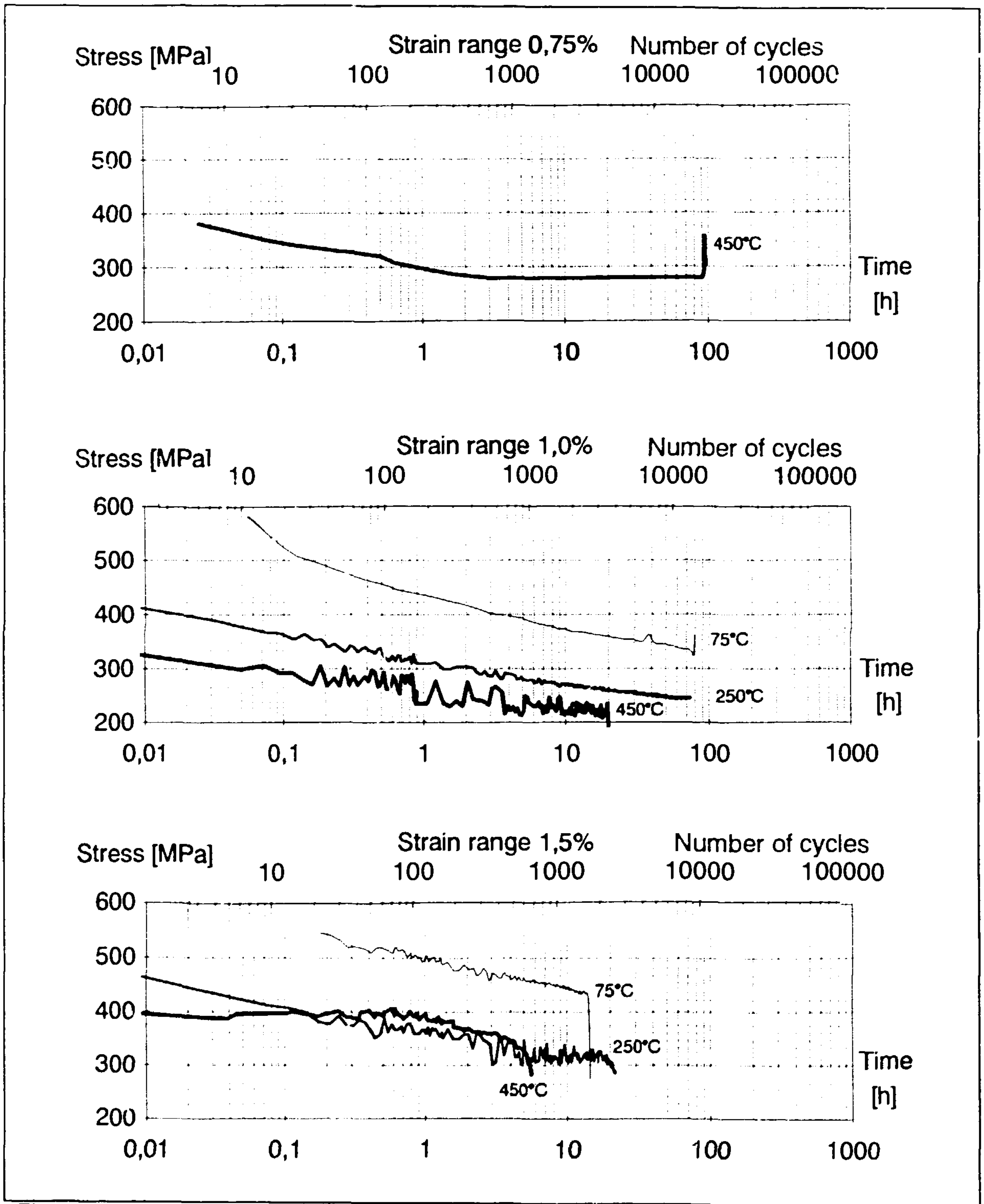

Figure B.4
Maximum stress versus time and number of cycles for irradiated plate material.

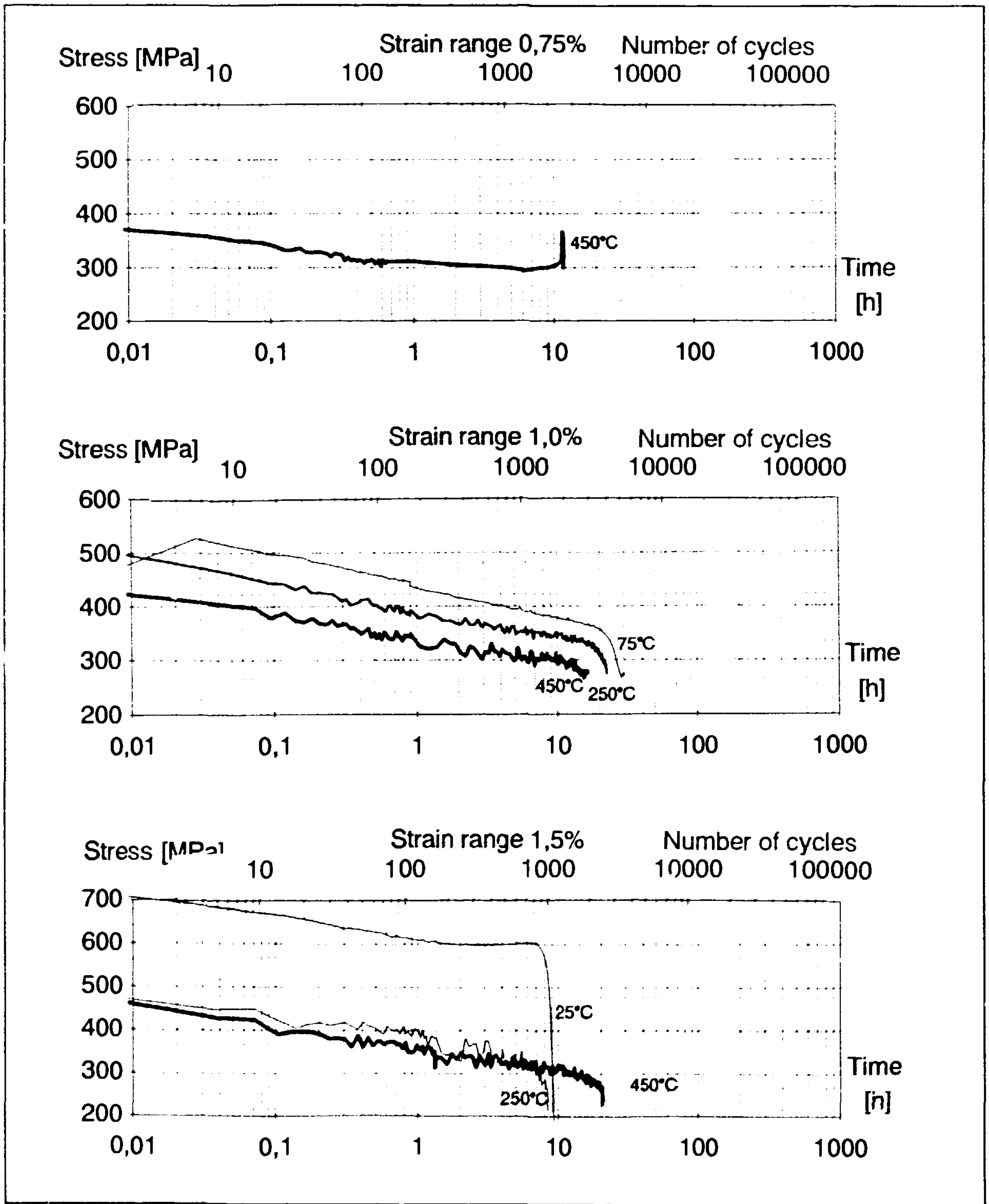

Figure B.5
Maximum stress versus time and number of cycles for irradiated weld material.

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